SubsurfaceTopics

INEEL Subsurface Science Initiative

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In This Issue

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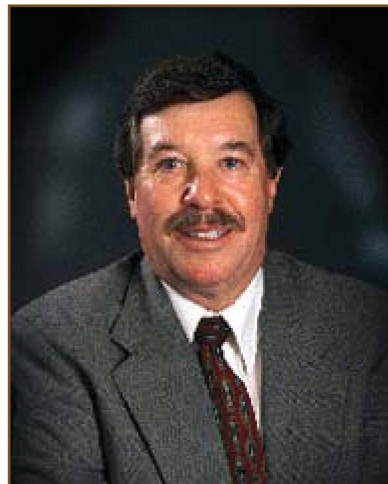
A Call to Action —
Advancing the Subsurface Science Research Agenda

Today we are facing many important societal needs — needs that directly affect this and future generations:

- Long-term protection of surface and groundwater supplies
- Safe long-term containment of hazardous materials in the subsurface
- Mitigation of intentional or accidental contamination of soils and waters
- Locating and extracting new energy and mineral resources
- Mitigation of global climate change.



P. Mike Wright, INEEL Subsurface Science Initiative Director

What do they have in common?

They all require vastly improved capabilities in the subsurface science fields — hydrology, geochemistry, microbiology, geology, geophysics, and their supporting disciplines.

The earth beneath our feet is a chemically and biologically active environment whose properties can be highly variable over short distances and times. Numerous individual, nonlinear, and often complex processes take place in this environment and many of these are coupled. Microbial activities, for example, may alter the hydraulic properties that govern fluid flow. And yet the mutual interdependence of physical, chemical, and biological properties remain poorly understood.

Despite recent advances, there are wide gaps between what we know and what we still need to know. We must develop a much better understanding of the physical, chemical, and biological processes, and the interactions taking place in the complex subsurface environment. We must have better methods for characterizing — mapping and visualizing — the heterogeneous subsurface environment in three dimensions.

Our lack of understanding has a serious consequence, which is that our best numerical models are unreliable. And yet we use numerical modeling to project the future outcomes of various disturbances to the subsurface, both common and esoteric. These range from the application of fertilizers or pesticides, the use of municipal landfills, and the migration of pollution from industrial sites; to the subsurface storage of chemical and radioactive wastes, and deep geologic storage of carbon dioxide to mitigate global warming.

(Action continued on page 3)

INEEL Chief Scientist and Geoscience Visionary Retires

Clayton R. Nichols, DOE-Idaho's chief scientist and assistant manager for research and development, officially retired from government service at the end of the 2002 fiscal year. During his 30-year career, Nichols was a strong advocate for geosciences research. Not only did he have the foresight to recognize the importance of geoscience to the Idaho National Engineering and Environmental Laboratory's (INEEL's) long-term mission, he also helped influence the INEEL's adoption of subsurface science as a major initiative.

Nichols thinks that the INEEL's geoscience capability is a prerequisite for the lab's success in many other fields. "No matter how much things change socially, politically, or even climatically, the INEEL cannot escape its geologic setting," Nichols said. "The site rests upon an aseismic plain of fractured basalt that contains an extremely important aquifer. Whatever course is charted for the INEEL, understanding its geologic setting and bounding the associated uncertainties are the keys to its future. Geoscience should always be viewed as a long-term enabling capability for the INEEL."

"Whatever course is charted for the INEEL, understanding its geologic setting and bounding the associated uncertainties are the keys to its future. Geoscience should always be viewed as a long-term enabling capability for the INEEL."

— C. Nichols,
DOE-Idaho chief scientist and assistant manager for research and development (retired)

Clay Nichols, recently retired DOE-Idaho chief scientist and assistant manager for research and development (front left), visits with U.S. Secretary of Energy Spencer Abraham (front right).

Nichols' dedication to geoscience is deeply rooted in his upbringing. His father, Paul Nichols, was a petroleum geologist and oil field pioneer who is often credited with modernizing rotary drilling by recording drilling variables. By the time young Nichols was 10 years old, he regularly accompanied his father on drilling rigs in the Oklahoma oil fields.

Nichols had completed three geoscience degrees at the University of Oklahoma by 1970 — a bachelor of science in geologic engineering, a master of science in geology studying clay minerals under Prof. Charlie Mankin, and a Ph.D. with a doctoral dissertation on the geology and geochemistry of geothermal systems. In addition, he held various positions as a visiting professor.

Nichols moved to Idaho in the early 1970s and began teaching at Boise State University. While there, he conducted research on geothermal phenomena of Yellowstone National Park. He has fond memories of a shared moment of discovery in his Boise office with Yale professor Dick Armstrong. Before Armstrong published his landmark paper on the Yellowstone hotspot and the origins of the Snake River Plain, he visited Nichols and shared his data showing the time sequence of volcanic calderas — data that showed the dates getting older with the distance from Yellowstone. With plate tectonics still in its infancy, Nichols immediately understood the significance of Armstrong's findings.

Nichols also made some rather fundamental discoveries of his own. While analyzing economically viable geothermal areas throughout the world, he theorized that the high temperatures needed to sustain dry steam and other types of geothermal plants would only exist where there was shallow melting of the continental crust.

"Whenever I stated my case to an audience, someone would point out the problem of Iceland," said Nichols. "Since I primarily focused on geothermal development and not geothermal research, I finally stopped pressing it. But I am pleased that a tiny vestige of continental crust associated with high-temperature geothermal areas in Iceland was finally identified. I didn't get a publication, but the theory, which I shared with several colleagues, was vindicated."

While at Boise State, Nichols began what would become a long involvement with the INEEL, helping it emerge from its nuclear energy roots to become the multiprogram national laboratory it is today. He also began consulting on the potential development of geothermal resources at the Nuclear Reactor Testing Station, now the site of the INEEL.

In 1974, after the Atomic Energy Commission became the Energy Research and Development Administration (ERDA), Nichols was invited to help organize ERDA' s national geothermal program in a joint effort with the United States Geological Survey (USGS). At that time, ERDA was responsible for engineering; the USGS was responsible for basic research. The Raft River Geothermal Power Plant demonstration in Idaho and other geothermal projects were the INEEL's first steps toward investigating energy sources other than nuclear power.

Nichols' interests broadened when ERDA was replaced by DOE. In addition to geothermal work, he participated in electrical vehicle research, industrial energy conservation, and early research into alcohol fuels. He directed DOE's Grand Junction office during its transition to managing uranium mill tailings projects and worked with the state of Alaska in managing its geothermal exploration program. Later, he led an interagency committee that investigated trade-offs between energy development and related environmental impacts.

In the late 1980s, Nichols' belief in the importance of geosciences was reinforced. He was leading an evaluation of the environmental impacts presented by DOE's proposed Special

(Nichols continued on page 4)

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Our models fail because of our present lack of knowledge. They do not incorporate the full range of subsurface processes and some processes may even be incorrectly incorporated.

Despite this, numerical models are being used for many purposes that presuppose knowledge of subsurface properties and processes: to determine the performance of the Yucca Mountain storage site, to guide the cleanup of contaminated DOE sites across the United States, and to judge the lifetimes over which aquifers will be able to furnish clean water. To the extent these models are unreliable, our society and ecosystem are at risk.

How can this be fixed? We know what the problem areas are, but we need increased resources to address them.

First, we need $100 million or more per year in additional funding for research and new research infrastructure. This could be spread across several agencies and made available to national laboratories, academic institutions, and the private sector.

Second, the research agenda should include and take full advantage of ongoing research activities. Because of the subsurface's inherent complexity, the enhanced research program's tenet should be a multidisciplinary research approach.

Third, the program should fully utilize the advanced computing technologies being developed largely through the DOE.

Are we ready to take on this task? Yes, federal agencies, the National Academy of Sciences, and other organizations have identified the knowledge gaps that must be addressed. In one area alone — cleanup and stewardship of contaminated DOE sites — at least a half dozen studies published in the last five years have recommended research activities and programs. Numerous studies of global climate change have defined unknowns and studies of the water cycle have been proposed.

The DOE report *"Research Needs in Subsurface Science"* (National Research Council, 2000) has already suggested improving coordination among the 14 key organizations conducting subsurface-related research. Though research organizations compete for a limited amount of research dollars, a more systematic approach to resource allocation would offer considerable potential for synergies.

The time for action is now. Research programs that can help ensure clean water for the future, guide our society's quest for increasing energy supplies, and help develop solutions to global warming will have a large, positive return on investment.

Through the INEEL Subsurface Science Initiative, we will help define a national agenda to justify and promote a major increase in funding for subsurface science research. If you agree and feel you are in a position to make a difference, please contact me so we can discuss ways to move this agenda forward.

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The DOE Environmental Management Science Program National Research Council report titled "Research Needs in Subsurface Science" is available online at http://www.nap.edu/books/0309066468/html/.

(Nichols continued from page 3)

Isotope Separation Project (SIS).

"At the time, some advocates wanted the Snake River Plain zoned as a high seismic hazard area," said Nichols. "This would have forced the government to completely and unnecessarily overbuild facilities, foreclosing the future development of nuclear facilities. It was only through the tireless work of INEEL geoscience professionals like geophysicist Suzette Payne and others that we were able to present the scientific evidence needed to support a designation matching the geologic reality."

Most recently, Nichols participated in the national vadose zone roadmapping effort. The roadmap identifies DOE's research needs for the next quarter century in the area of fate and transport of materials in the unsaturated subsurface.

These accomplishments, and his seminal role supporting the INEEL's Subsurface Science Initiative, have allowed Nichols to retire satisfied that he has served his discipline well. Though he still gets together weekly with his peers from DOE and the USGS, Nichols thinks he will be happy with life at home. When asked if he will miss his active role as a scientist, Nichols said, "I may not think of myself as a scientific researcher anymore, but I will always appreciate and be a student of good science."

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2nd Annual INRA/INEEL Subsurface Science Symposium

More than 200 researchers, professors, and students converged in Boise, Idaho, this past October for the 2nd Annual Inland Northwest Research Alliance (INRA)/INEEL Subsurface Science Symposium. The conference theme was mesoscale research, an emerging geoscientific experimental approach that proponents believe could bring new insight into scaling issues. Scaling is the process of determining quantitative values for a large system based on data obtained from a system that is orders of magnitude smaller.

> *"Mesoscale experiments are the tools we need to make breakthroughs in understanding the subsurface environment."*
>
> *— M. Wright, INEEL SSI Director*

Many researchers believe that pilot-scale, or mesoscale, experiments may more closely mimic the complexity of the real world. These experiments are larger in size than traditional experiments, yet they still enable researchers to maintain control of experimental variables.

"Mesoscale experiments are the tools we need to make breakthroughs in understanding the subsurface environment," said Michael Wright, Director of INEEL's Subsurface Science Initiative, at the conference's opening session. "They promise new approaches to difficult and longstanding problems."

Traditional geoscience breaks complex field behavior into discrete, easily understood pieces that can be studied on the laboratory bench. However, laboratory data tend to be simplistic, limited in scope, and often do not 'scale up' to explain field behavior. Also, hydrological, chemical, physical, and biological subsurface processes are both interactive and co-dependent, so studying any process while excluding others often yields incomplete results.

On the other hand, when the controlled environment of a mesoscale test bed is used to develop and calibrate geophysical instruments, for example, researchers are able to quantify the influence of variables affecting measurement accuracy and range. These variables could include the air in the borehole, well casing materials, soil composition, or water in the media. The ability to mathematically weigh these variables' influence helps determine sampling and imaging strategies. Ultimately, it results in more accurate models.

Another speaker at the symposium was Hans-Peter Koschitzky, the technical director of the VEGAS Institute at the University of Stuttgart, Germany. One of the major research focuses at VEGAS is in situ remediation technologies.

Koschitzky described how VEGAS is using mesoscale experiments to improve their understanding of scaling factors, including how the effects of various subsurface processes change when they are evaluated at increasingly larger spatial scales over longer time frames. The institute's researchers are using mesoscale tanks to test different remediation approaches for nonaqueous phase liquids in the vadose zone. The tanks provide test beds comparable to a natural environment and can be filled using realistic soil profiles. They also allow hydraulic boundary conditions to be controlled and field monitoring equipment to be used.

Wright said one reason for INEEL's

emphasis on mesoscale investigation is that the current infrastructure of subsurface science research is inadequate for solving the complex problems we face. During the past two years, the INEEL has addressed this by developing an array of new mesoscale research capabilities. These include a 2-meter, 50-gravity-tonne capacity geocentrifuge for fluid infiltration

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>
> — *M. Wright, INEEL SSI Director*

studies; large-scale tanks for geophysical instrument development and calibration; and a vadose zone research park featuring infiltration monitoring wells.

Wright noted that mesoscale investigations and a multidisciplinary approach both present new challenges. Old testing strategies become irrelevant and gaps in knowledge and capabilities become quickly apparent. An increased array of variables and processes can be measured, and data management grows increasingly challenging. "We're in the throes of learning how difficult it is to design and conduct mesoscale research," said Wright, "but we're prepared for the challenge."

Participants at the INRA/INEEL's 2nd Annual Subsurface Science Symposium shared experiences in mesoscale issues: INRA leaders Steve Billingsley and Gautam Pillay talk with keynote speaker Stephen Wells (top); a participant visits with Russ Hertzog of the INEEL's SSI (middle); and Stephen Wells (bottom) leads a plenary session (see related article on page 8).

Symposium Participants Hear Wide Variety of Mesoscale Research Experiences

The Symposium offered participants an opportunity to learn from a wide variety of mesoscale research experiences. Russel Hertzog, the INEEL SSI's technical lead for geophysical research and one of the Symposium's coordinators, helped select the session leaders. "The presenters didn't always use the term 'mesoscale' to define their research, but they are all focusing on how to move from a detailed, small model to an accurate, larger model," said Hertzog. "There was a lot of discussion and interaction. The Symposium was a success."

Geophysicist Rosemary Knight, from Stanford University, launched the Geophysics session with a discussion of moving from laboratory to field scale with respect to spatial heterogeneity in geophysical data.

Hydrogeologist Roger Beckie, from the University of British Colombia, spoke about the relationship between measurements at different scales in the Scaling session.

Civil engineer Tissa Illangasekare, from the Colorado School of Mines, spoke about physical modeling as a way to investigate the role of heterogeneity at DNAPL sites and demonstrate the need for up-scaling in the Mass Transport session.

Biologist Terry Hazen, from Lawrence Berkeley National Laboratory, discussing scaling issues in the Bioremediation session, particularly transitioning from in situ bioremediation research to practical applications in the field.

Chemist Sue Clark, from Washington State University, discussed the development of analytical methods for studying actinide partitioning in soils and sediments in the Geochemistry session.

Don Morton, from the University of Montana, spoke about using dynamically adaptive grids for subsurface processes modeling in the Modeling session.

INEEL hydrologist Earl Mattson discussed using a centrifuge to study two-region mass transport in unsaturated porous media in the Hydrology session.

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New Microbe Marker Technique Benefits Environmental Research

INEEL microbiologist Joni Barnes works at her microscope. To visualize GFP-tagged microbes, she and her team developed effective epifluorescent and laser confocal microscopy methods that allow real-time monitoring of the GFP-tagged populations.

Visualizing a problem is often the key to seeing its solution. An INEEL research team is using a gene cloned from a northern pacific jellyfish to provide useful illumination. The gene — which codes for green fluorescent protein (GFP) — is being used as a molecular marker. The marked bacteria brightly fluoresce, making them easy to see using epifluorescent or confocal microscopy.

Conventional techniques for visualizing bacteria require preparation steps that are often toxic to the cells and can change bacterial surface properties. "We are working to create new, non-invasive tools for the environmental microbiologist," said INEEL microbiologist and team leader Joni Barnes. "GFP tagging has great potential. It can be used for anything from studying the dynamics and distributions of microbial populations to developing biosensors." (See sidebar about biosensors.)

"GFP tagging has great potential. It can be used for anything from studying the dynamics and distributions of microbial populations to developing biosensors."

— J. Barnes, INEEL microbiologist

GFP is widely used in the research community as a reporter gene for tracking cells and assessing metabolic activity in plants, animals, and bacteria. The gene is an excellent marker because the cells make the protein and generate fluorescence without researchers having to introduce other chemicals.

To mark environmental microbes with the GFP gene, Barnes and her team use plasmid cloning vectors. Plasmids — small, genetic elements that reside in bacteria and replicate independently from the chromosome — can be manipulated and modified in the laboratory to carry genes of interest that can then be inserted into host bacteria. These genes can provide the organism with specific traits, such as resistance to antibiotics or heavy metals.

The team constructed a plasmid that carries both the GFP gene and a gene for tetracycline resistance and can be inserted into a broad range of bacteria using chemical or electrical techniques. Then they grew the cells in the presence of the antibiotic tetracycline to identify clones that carried the GFP plasmid.

Barnes is also interested in learning more about the research potential offered by other fluorescent proteins, including GFP variants that produce blue, cyan, and yellow fluorescent proteins and a red fluorescent protein recently isolated from sea anemones. The variants have different chemical properties, maturation rates, and color intensities in addition to producing a variety of colors. "Because these proteins have different fluorescent excitation and emission spectra,

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— J. Barnes, INEEL microbiologist

researchers could use different colored tags to simultaneously monitor the interaction of up to three unique cell populations present in a mixed culture," said Barnes.

The variants also give researchers the ability to customize their experiments. "Colors could be used that offer better visual contrast with the background," said Barnes. "For example, in mineral samples that appear yellow under epifluorescent light, a blue glow would be more easily detected than a yellow glow."

One of Barnes' goals is to define the advantages and limitations of each protein under environmental conditions. She would also like to develop techniques for their use in laboratory and field studies as well as biosensor development.

So far, Barnes and her team have successfully tagged several different bacterial species with GFP, including iron, sulfate,

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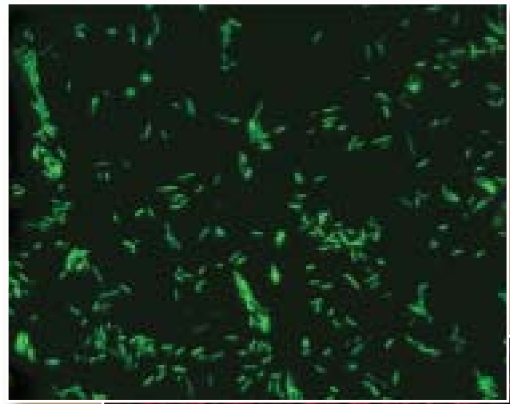

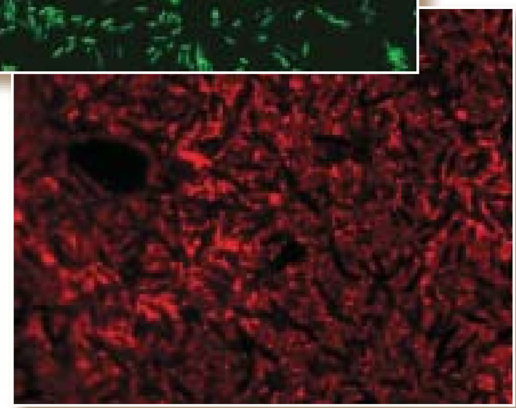

Two epifluorescent photomicrographs show the results of using plasmid cloning vectors to mark environmental microbes with the GFP gene. The top photomicrograph shows iron-reducing bacteria,** Shewanella putrefaciens,* ***attached to a hematite surface. The GFP-tagged cells were grown for 44 hours in a laminar flow cell operated under aerobic conditions. The bottom photomicrograph shows a microbial biofilm composed of** E. coli* ***cells tagged with red fluorescent protein.

INEEL Researchers Begin Developing an Environmental Arsenic Biosensor

An INEEL research team, led by molecular biochemist Frank Roberto, has been working on a biosensor for arsenic. Biosensors are devices that use biological molecules to detect other biological molecules or chemical substances. The results can be measured either qualitatively or quantitatively. If a biosensor monitoring technique was available, it could potentially reduce the high costs currently associated with arsenic monitoring.

The team began by identifying microbes tolerant to arsenic. These microbes produce various protein enzymes that allow them to survive. Since their biochemical survival mechanism is genetically determined — their toxic-response genes are organized as operons, which are controlled by genetic trigger mechanisms called promoters — marking the location with a reporter gene offered a potential biosensor system.

The team isolated the toxic-response genes for the bioavailable compounds arsenate and arsenite. Then they co-located the GFP reporter gene behind the promoter for arsenic resistance. When the microbes were exposed to arsenic, the biosynthesis of proteins was triggered, as well as the production of GFP with its characteristic glow. The team was able to detect submicrogram quantities of arsenate and arsenite compounds at concentrations relevant to public health concerns and current regulations.

According to Roberto, their research effectively demonstrated that inexpensive, effective whole cell biosensors can be produced. "Biosensors may not replace accepted methods of instrumental analysis," said Roberto. "But they have significant potential and may eventually offer a low-cost alternative. That alone is reason to continue this line of research."

Results of the team's research were recently published in *Talanta*[1], the international journal of pure and applied analytical chemistry.

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1. *Roberto, F.; J. Barnes; D. Bruhn.* Evaluation of a GFP reporter gene construct for environmental arsenic detection. *2002, Talanta, 58, p.181-188.*

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and nitrate reducers. These groups of microbes are environmentally significant because they influence contaminant mobility in the subsurface. To visualize these labeled cells, the team developed effective epifluorescent and laser confocal microscopy methods that allow real-time monitoring of the GFP-tagged populations.

> *"Bacterial strains should be chromosomally marked for long-term use or field studies. Chromosomal marking maximizes genetic stability and reduces the chance that the GFP marker will be transferred to other microbes."*
>
> — J. Barnes, INEEL microbiologist

GFP plasmids clearly provide an effective means of tagging environmental bacteria for use in short-term studies. However, according to Barnes, "Bacterial strains should be chromosomally marked for long-term use or field studies. Chromosomal marking maximizes genetic stability and reduces the chance that the GFP marker will be transferred to other microbes."

In anticipation of field studies, the team is currently using transposon mutagenesis to insert the GFP gene onto the chromosome of environmental bacteria. So far, the team has tagged the *Pseudomonas putida F-1* chromosome, a microbe capable of degrading trichloroethene.

Transposon: a piece of DNA that has the ability to move from one

"New tools and techniques often lead to new discoveries," said Barnes. "We expect that the use of GFP will increase our understanding of microorganisms in the environment and be very useful for environmental research."

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This research is funded by the INEEL's Laboratory Directed Research and Development (LDRD) program. It is being conducted by INEEL researchers Joni M. Barnes; Frank Roberto, Ph.D; Debbie Bruhn; and Bill Bauer, Ph.D.

2nd Annual INRA/INEEL Symposium Keynote Topic

Desert Pavement — The Key to Man-made Barriers?

The interaction of surface and subsurface processes in the development of desert pavements was the topic of the Symposium's keynote address. The speaker, Stephen Wells of the Desert Research Institute in Reno, Nev., shared his fascination with desert pavements — a fascination that has resulted in his characterization of pavements around the world. "This natural barrier could be the key to designing caps over contaminated sites that will stand the test of time," said Wells.

Desert pavement — a thin mantle of packed rock — blankets almost 50 percent of the world's arid land. Over time, both weathering and a visible 'varnished' look from iron and manganese oxides causes the pavement stone to appear quite different from the underlying parent stone.

Researchers have long thought that desert pavements formed through wind-induced surface erosion, leaving the rocks in place after the fines have blown away. Wells and his research team believe otherwise.

Wells explained that they think the armorlike surfaces of the pavement are caused by the buildup of dust particle accumulations in microfractures. The dust slowly lifts the rubble material upward, creating definable accretionary layers and, ultimately, a crust of rock.

The team's research shows that highly-developed pavements allow very little water infiltration into the subsurface, control vegetation growth, and discourage runoff. Recreating the pavement growth process may be the key to designing effective long-term infiltration controls for man-made barriers (caps) at contaminated sites. Wells believes that volumetric dilation — soil particles getting stuffed into cracks — also needs to be factored into the design because it is part of the aging process for this natural surface barrier.

Wells and his team are currently investigating quantitative methods for determining the age of pavement material to learn more about structural stability. Ultimately, Wells hopes to use these natural barriers to predict the mesoscale spatial variability of infiltration potential for a given area.

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More information about research at the Desert Research Institute is available at http://www.dri.edu/

New Instrument Reveals Information about Colloids

The flashes, clicks, and pops of colloids being zapped may look and sound similar to the common backyard bug zapper, but they are shedding light on what has long been a subsurface mystery. An INEEL research team is using laser-induced breakdown spectroscopy and acoustic monitoring to study colloids, submicron particles in the subsurface environment.

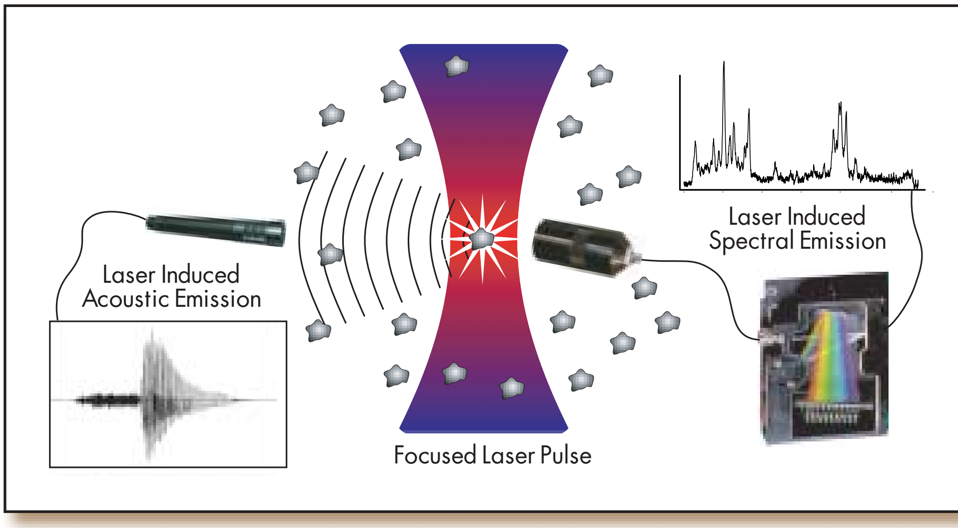

Figure 1. An INEEL research team is incorporating laser-induced breakdown spectroscopy and acoustic monitoring detection (illustrated above) into a measurement system for studying colloid transport. The system will eventually be packaged for borehole deployment.

It is well-known that colloids have the potential to influence contaminant transport, but there is a lack of comprehensive understanding of the mechanisms. Current modeling approaches underestimate, or even ignore, colloid-facilitated transport mechanisms, yet colloids are frequently offered as the explanation for why some contaminants move faster than we expect.

One reason for the lack of understanding is the difficulty in observing colloids in natural environments, especially without affecting their behavior. "Right now, our ability to study colloids is extremely limited," said INEEL physicist Judy Partin. "Just the act of pumping a well and sucking out a water sample can disturb colloids that might not be mobile and introduce a sampling bias. Existing analytical techniques are time-consuming and expensive. Samples need to be taken at a very specific moment to understand how emergent events like precipitation affect colloidal transport. Colloids simply cannot be efficiently measured in real-world conditions, but we hope to change that."

INEEL researchers — led by Partin and including INEEL environmental chemist George Redden and physicist Jim Davidson — are developing a technique based on previous research conducted in Germany. The German technique uses laser-induced breakdown spectroscopy to direct a very intense pulse of laser light into a water sample. If a colloid particle is at the focal point, it is vaporized and emits light and sound — a phenomenon called laser-induced breakdown.

> *"For us, what is exciting is this instrument will enable researchers to gather real-time data from an environment that currently is beyond our reach."*
>
> *— J. Partin, INEEL physicist*

Laser-induced breakdown occurs when the electric field at the focus of a high-energy laser pulse exceeds the dielectric constant of the target material. When this happens, the material absorbs the energy and ionizes, forming plasma. The plasma becomes opaque and absorbs more laser energy, resulting in a bright arcing flash and shock wave. The flash's spectrum can be analyzed to determine material composition; the shock wave's audible popping sound can be related to the particle size.

For colloidal matter suspended in water, the laser pulsing at 10 to 1,000 times per second acts like a bug zapper. When a colloid particle strays into the laser's path, it gets zapped. The higher the concentration of particles, the more frequently the flash and pop. The German team reported detecting colloids in a 10- to 1,000-nanometer size range at the parts-per-trillion level using this technique.

Partin and her colleagues are using spectroscopy to determine the composition of colloid particles. An optical fiber carries the spectral emission that results from the vaporization, ionization, and subsequent relaxation of the particles' chemical constituents to an emission spectroscope.

(Colloids continued on page 10)

(Colloids continued from page 9)

"There is a lag of about 100 nanoseconds between the laser pulse, the formation of the plasma arc, and the development of the emission lines, so we use a high-speed, gated data acquisition system to ensure we get a good spectra," said Partin.

"Ionic spectra form first, followed by the atomic spectra of elements," she said. "We can selectively examine the data by adjusting the time range on the gate from several nanoseconds up to 100 microseconds after the laser pulse."

In order to detect low concentrations of colloids and also determine their composition, the team has combined the laser spectroscopic capability with acoustic measurements. Recently, the team has been working to increase the system's sensitivity.

"Ideally, we will not only have the ability to determine the colloid's bulk composition, but also the composition of any species that is sorbed onto a colloid particle," said Redden. "With this technique, we might even be able to observe colloid movement, learn what mobile colloids are transporting, and understand how episodic or seasonal events affect their migration."

The team is particularly interested in colloidal species with a very high specific surface-to-mass ratio that are very effective sorbents for metals or other contaminants, and colloidal species formed directly from toxic or radioactive substances, such as heavy metals. Colloidal transport of actinide species may be responsible for sporadic and otherwise unexplainable detections of plutonium and americium in groundwater samples collected at the INEEL. There is also evidence that plutonium at the Nevada Test Site is traveling much faster than expected as a colloidal oxide.

So far, the proof-of-concept experiments are promising and the team hopes to develop a prototype instrument capable of continuous monitoring within a year. Because the goal is to measure colloidal material in situ, the team's next challenge will be squeezing their instrument into a package that can be lowered into a borehole or into a mesoscale experiment.

"Some researchers were dubious about the challenge of taking in situ measurements with the system," said Partin. "But the beauty of optical instruments is their ability to remotely gather data."

Partin's confidence is rooted in her experience. She has built instruments for detecting aerosols generated by damaged nuclear fuel elements in an operating test reactor. "Compared to the high-temperature, high-pressure, and damaging radiation environment inside a working reactor, water in a subsurface borehole seems pretty accessible," said Partin.

When the new instrument is available for borehole use, it will enable the development of a fundamental understanding of how colloids influence contaminant transport. Modeling approaches will be able to factor in colloid-facilitated transport mechanisms and there will be fewer nasty cleanup surprises.

"The INEEL has superb engineering capabilities and building instruments like this is one of the things we do best," said Partin. "For us, what is exciting is this instrument will enable researchers to gather real-time data from an environment that currently is beyond our reach."

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This research is funded by the INEEL's Laboratory Directed Research and Development (LDRD) program. It is being conducted by Judy Partin, Ph.D; George Redden, Ph.D; and Jim Davidson (all from the INEEL).

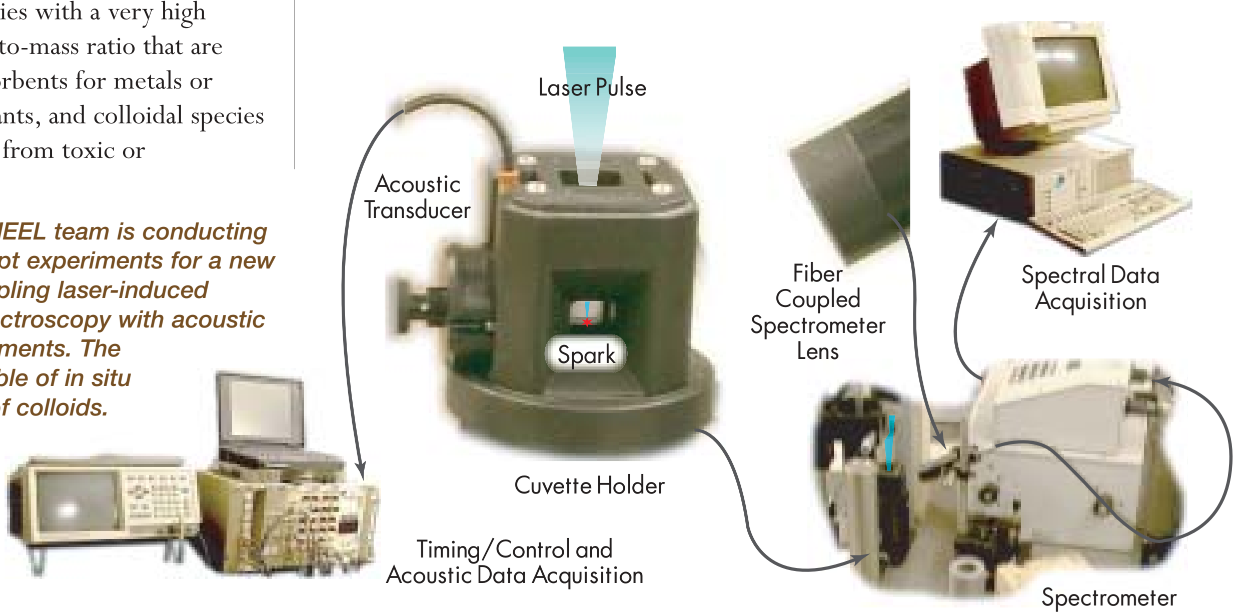

Figure 2. An INEEL team is conducting proof-of-concept experiments for a new instrument coupling laser-induced breakdown spectroscopy with acoustic signal measurements. The system is capable of in situ quantification of colloids.

Prioritizing Cleanup Research

— INEEL's Water Integration Project

The INEEL's Water Integration Project is conducting tours for stakeholders to help them understand the INEEL's complex hydrology. The Snake River Plain Aquifer flows beneath the INEEL and supplies drinking water for more than 200,000 people. The INEEL recently completed the first of a three-year effort to improve the coordination of research efforts and strengthen the technical basis for cleanup decisions.

"Coming together is a beginning. Keeping together is progress. Working together is success."

– Henry Ford

Aquifer contamination and cleanup efforts at the INEEL are more than just a passing interest for Idaho's citizens. The Eastern Snake River Plain Aquifer, which flows beneath the INEEL, is one of Idaho's largest and most vital natural resources. It irrigates crops, provides drinking water for more than 200,000 people, and supports the nation's largest trout farming industry.

In recognition of this unique resource, the INEEL formed the Water Integration Project, a three-year effort to improve coordination of research efforts and strengthen the technical basis for cleanup decisions.

The project team was given many challenges: increase data sharing, coordinate scientific research programs, consolidate groundwater monitoring data, improve the relevance of research to the cleanup program, and involve the public in the process.

> *"There is a lot of great research going on, but we need to be partners if we want the research to be more useful to the cleanup program."*
>
> — D. Burns, INEEL Water Integration Project project manager

One of the team's first actions was to resolve the conflicting hypotheses offered by existing conceptual models so they could develop a single conceptual model for the INEEL's subsurface geology and hydrogeology. A single model that encompasses the source term, vadose zone, and aquifer will help future researchers frame their questions and give the cleanup program a solid basis for improved decision-making.

"There is a lot of great research going on, but we need to be partners if we want the research to be more useful to the cleanup program," said Doug Burns, the project's manager. "We thought improving coordination and gaining a better understanding of our collective base of knowledge was the best place to begin."

Now in its second year, the project team has already completed the first step toward developing an INEEL-wide conceptual model by summarizing all existing knowledge and assumptions from the INEEL's subregional and facility-specific models. The summary — *"INEEL Subregional Conceptual Model Report; Volume 1–Summary of Existing Knowledge of Natural and Anthropogenic Influences Governing Subsurface Contaminant Transport in the INEEL Subregion of the Eastern Snake River Plain"* — is considered a 'living' document and will be adjusted as knowledge broadens.

The project team has included stakeholders throughout the process. INEEL advisory scientist Jan Brown coordinates their involvement. "You might think that building conceptual models and setting research priorities are beyond the reach of the average layperson, but you would be surprised at the knowledge outside the boundaries of the INEEL," said Brown. "Aquifer issues are at the top of the public's list of concerns and a recent social science survey indicates that one of five Idahoans wants to get more involved with INEEL waste issues. I am

> *"There are many more perspectives represented during discussions by having the stakeholders involved. The diversity has sharpened our perceptions of what is clearly known and what is missing."*
>
> — P. Wichlacz, INEEL researcher and Water Integration Project team member

(Water continued on page 12)

(Water continued from page 11)

confident stakeholders will continue to become engaged as knowledge of the project expands."

INEEL researcher Paul Wichlacz, who is leading the coordination effort to develop the single conceptual model, said stakeholder involvement has definite benefits. "There are many more perspectives represented during discussions by having the stakeholders involved," said Wichlacz. "The diversity has sharpened our perceptions of what is clearly known and what is missing."

To bring the effort 'alive,' the project team is conducting site tours to help stakeholders understand the complexity of INEEL hydrology. Burns believes the tours and other forms of public outreach have established the relationships and network the project needs to continue collaborative learning.

"We have begun a dialogue with a wide array of stakeholders," said Burns. "As they learn about the aquifer system, we learn more ourselves. We have definitely laid the groundwork for more effective communication when issues come up in the future."

The next task for the team is to develop specific research hypothesis 'science strategies.' These will be based on a September 2001 draft roadmap and its September 2002 supplement, which identified gaps in knowledge, determined the science and technology needs related to site cleanup, and prioritized capabilities to better focus research efforts.

"We have concluded that if we want research to be more meaningful to our program, we have to be a partner in defining the research questions," said Burns. "By the end of the fiscal year, we hope to start issuing research calls based on our science strategies."

> ***"By the end of the fiscal year, we hope to start issuing research calls based on our science strategies."***
>
> *— D. Burns, INEEL Water Integration Project project manager*

The team plans for the science strategies to be sponsored by the cleanup program. Because the concept is a new one, the team intends to use external peer-reviewers to ensure the calls and resulting research are useful for both the cleanup program and scientific community. "If we want researchers to help solve our problems, we have to play by the rules of the research community," said Burns. "Peer review will be an important factor in the development and evaluation of new research projects."

According to Burns, the cost of integration and coordination is nothing when compared to the efficiencies and benefits that have resulted. "For example, because of our involvement with the water user community, our view of the aquifer has changed," said Burns. "We used to see it solely as an INEEL cleanup issue. Now we see it as a significant shared natural resource. It may sound simple, but there has been a fundamental shift in our thinking."

More information about the INEEL Water Integration Project is available at http://www.inel.gov/environment/water/.

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